MOISTURE CONTENT AND HUMIDITY MEASUREMENT

Module 5

Moisture content Definition

- It is the quantity of water contained in a material like soil (soil moisture), rock, ceramics and wood.
- Moisture content is expressed as a ratio, which can range from 0(completely dry) to the value of the materials' porosity at saturation.
- Moisture content can be given on a volumetric or mass(gravimetric) basis.

Moisture content(θ) is calculated either on volumetric basis:

$$\theta = \frac{V_w}{V_T}$$

V_w = Volume of water and $V_T = V_s + V_v = V_s + V_w + V_a$ is the total volume (that is soil volume + water volume + air space).

Or it is calculated on mass (gravimetric basic):

$$u = \frac{m_w}{m_t}$$

Where m_w is the mass of water and m_t is the bulk mass.

Moisture content determination by thermal drying

Water content can be directly measured using a known volume of the material, and a drying oven. Volumetric water content, θ, is calculated using:

$$\theta = \frac{m_{\text{wet}} - m_{\text{dry}}}{\rho_w \cdot V_b}$$

Where,

m_{wet} and m_{dry} are the masses of the sample before and after drying in the oven;

ρ_w is the density of water; and

V_b is the volume of the sample before drying the sample.

For materials that change in volume with water content, such as coal, the water content, u, is expressed in terms of the mass of water per unit mass of the moist specimen:

$$u = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{wet}}}$$

Applications

- Coal dust or wood chips in furnaces
- Transport and charging of waste material
- Storage of crops and fertilizers
- Processing of powders in pharmaceutical industries
- Processing of corn, milk powder , coffee etc in the foodindustry

Humidity

- Humidity is the amount of water vapor present in the air.
- Humidity indicates the likelihood of precipitation, dew, or fog.
- Humidity can be classified into :
- Absolute Humidity
- Relative Humidity
- Absolute humidity is the total mass of water vapor present in a given volume of air. It does not take temperature into consideration.
- Absolute humidity in the atmosphere ranges from near zero to roughly 30grams per cubic meter when the air is saturated at 30°C (86°F).
- Absolute humidity is the mass of the water vapor , divided by the volume of the air and water vapor .
- The absolute humidity changes as air temperature or pressure changes.
- This makes it unsuitable for chemical engineering .

Relative humidity

- Relative humidity(RH) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature.
- Relative humidity depends on temperature and the pressure of the system of interest.
- The relative humidity (RH) of an air–water mixture is defined as the ratio of the partial pressure of water in the mixture to the equilibrium vapor pressure of water a flat surface of pure water at a given temperature.
- Relative humidity is normally expressed as a percentage ; a higher percentage means that the air–water mixture is more humid; a lower percentage means that the air-water mixture is less humid .

Types of hygrometers

Classical Hygrometer's

1. Metal-paper coil type
2. Hair tension hygrometer
3. Pyschrometer (wet and dry bulb hygrometer) : Sling pyschrometer
4. Chilled mirror dew point hygrometer

Modern Hygrometer's

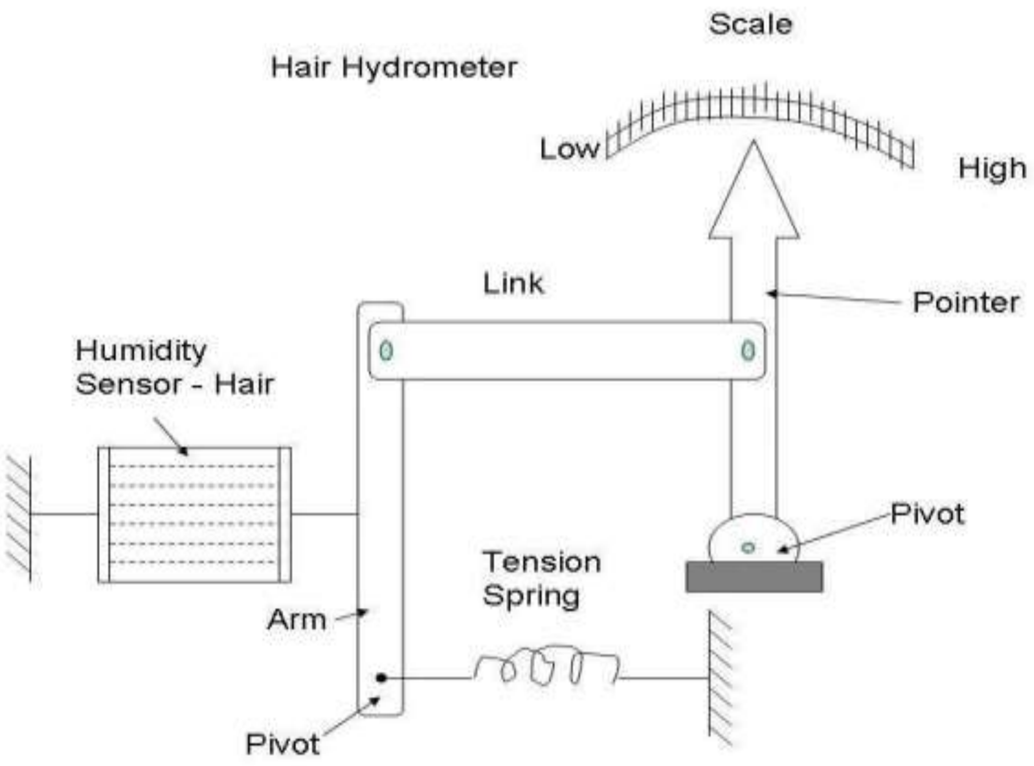
1. Capacitive
2. Resistive
3. Thermal
4. Gravimetric

Hygrometer

- A hygrometer is an instrument used for measuring the moisture content in the atmosphere.
- Humidity measurement instruments usually rely on measurements of some other quantity such as temperature, pressure, mass or a mechanical or electrical change in a substance as moisture is absorbed.
- By calibration and calculation, these measured quantities can lead to a measurement of humidity.
- Modern electronic devices use temperature of condensation (the dew point), or changes in electrical capacitance or resistance to measure humidity differences.

Hair hygrometer

- Human hair is used as the humidity sensor.
- The hair is arranged in parallel beam and they are separated from one another to expose them to the surrounding air/atmosphere.
- Number of hairs are placed in parallel to increase mechanical strength.
- This hair arrangement is placed under small tension by the use of a tension spring to ensure proper functioning.
- The hair arrangement is connected to an arm and a link arrangement and the link is attached to a pointer pivoted at one end.
- The pointer sweeps over a humidity calibrated scale.
- Human hair has a property that its length increases when it is wet and its length decreases when it goes dry .



Operation

- When the humidity of air is to be measured, this air is made to surround the hair arrangement and the hair arrangement absorbs the humidity from the surrounding air and expands or contracts in the linear direction.
- This expansion or contraction of the hair arrangement moves the arm & link and thus the pointer to a suitable position on the calibrated scale and thus indicating the humidity present in the air/atmosphere.
- These Hair hygrometers are called membrane hygrometers when the sensing element is a membrane.

Applications

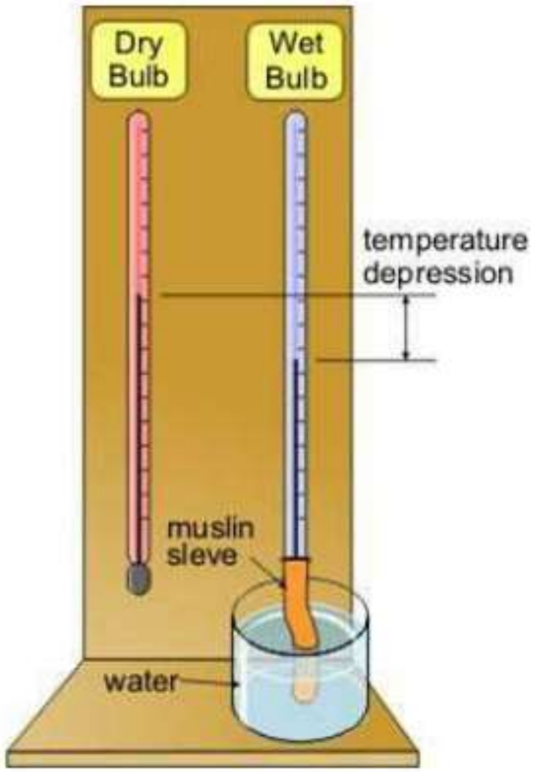
- These hygrometers are used in the temperature range of 0'C to 75'C.
- These hygrometers are used in the RH (Relative Humidity) range of 30 to 95%.

Disadvantages

- These Hygrometers are slow in Response .
- If the Hair hygrometer is used constantly, its calibration tends to change.

Wet & Dry Bulb Hygrometer

- A pyschrometer or wet & dry bulb thermometer , consist of two thermometers , one that is kept moist with distilled water on a sock or wick .
- At temperatures above freezing point of water, evaporation of water from the wick lower temperatures so that the wet-bulb usually shows a lower temperature than that of the dry-bulb thermometer .
- When the air temperature is below freezing , however the wet-bulb is covered with a thin coating of ice and may be warmer than the dry bulb .



Relative Humidity Equation

$$e_d = 6.112 * e^{\left(\frac{17.502 \ * \ T_d}{240.97 \ + \ T_d}\right)}$$

$$e_w = 6.112 * e^{\left(\frac{17.502 \ * \ T_w}{240.97 \ + \ T_w}\right)}$$

$$\text{Relative Humidity} = \frac{e_w - N*(1+.00115*T_w)*(T_d - T_w)}{e_d} * 100$$

e = 2.71828182845904

T_d = Dry Bulb Temperature (Celsius)

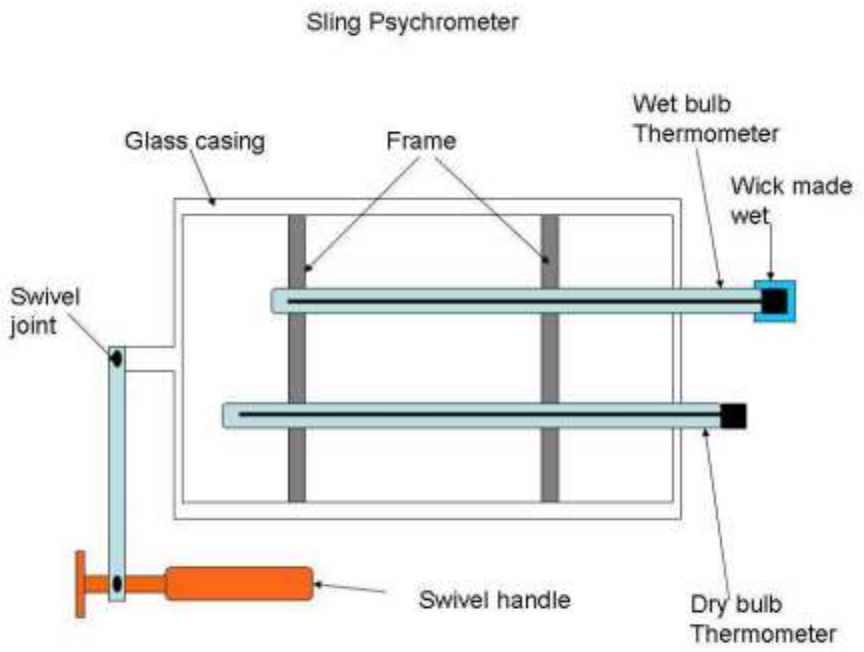
T_w = Wet Bulb Temperature (Celsius)

N=.6687451584

Sling psychrometer

- A sling psychrometer, which uses thermometers attached to a handle or length of rope and spun in the air .
- In order to measure the dry bulb and wet bulb temperature, the Psychrometer frame –glass covering – thermometer arrangement is rotated at 5 m/s to 10 m/s to get the necessary air motion.
- The thermometer whose bulb is bare contacts the air indicates the dry bulb temperature.
- At the same time, the thermometer whose bulb is covered with the wet wick comes in contact with the air and when this pass on the wet wick present on the bulb of the thermometer, the moisture present in the wick starts evaporating and a cooling effect is produced at bulb.
- Now the temperature indicated by the thermometer is the wet bulb thermometer which will naturally be lesser than the dry bulb temperature.

- If the Psychrometer is rotated for a short period, then the wet bulb temperature recorded will not be proper.
- If the Psychrometer is rotated for a longer period, the wick will get dried soon and the wet bulb temperature will not be at its minimum value.



Applications

- It is used for checking humidity level in air-conditioned rooms and installations.
- It is used to set and check hair hygrometer.
- It is used in the measurement range of 0 to 100% RH.
- It is used for measuring wet bulb temperature between 0'C to 180'C.

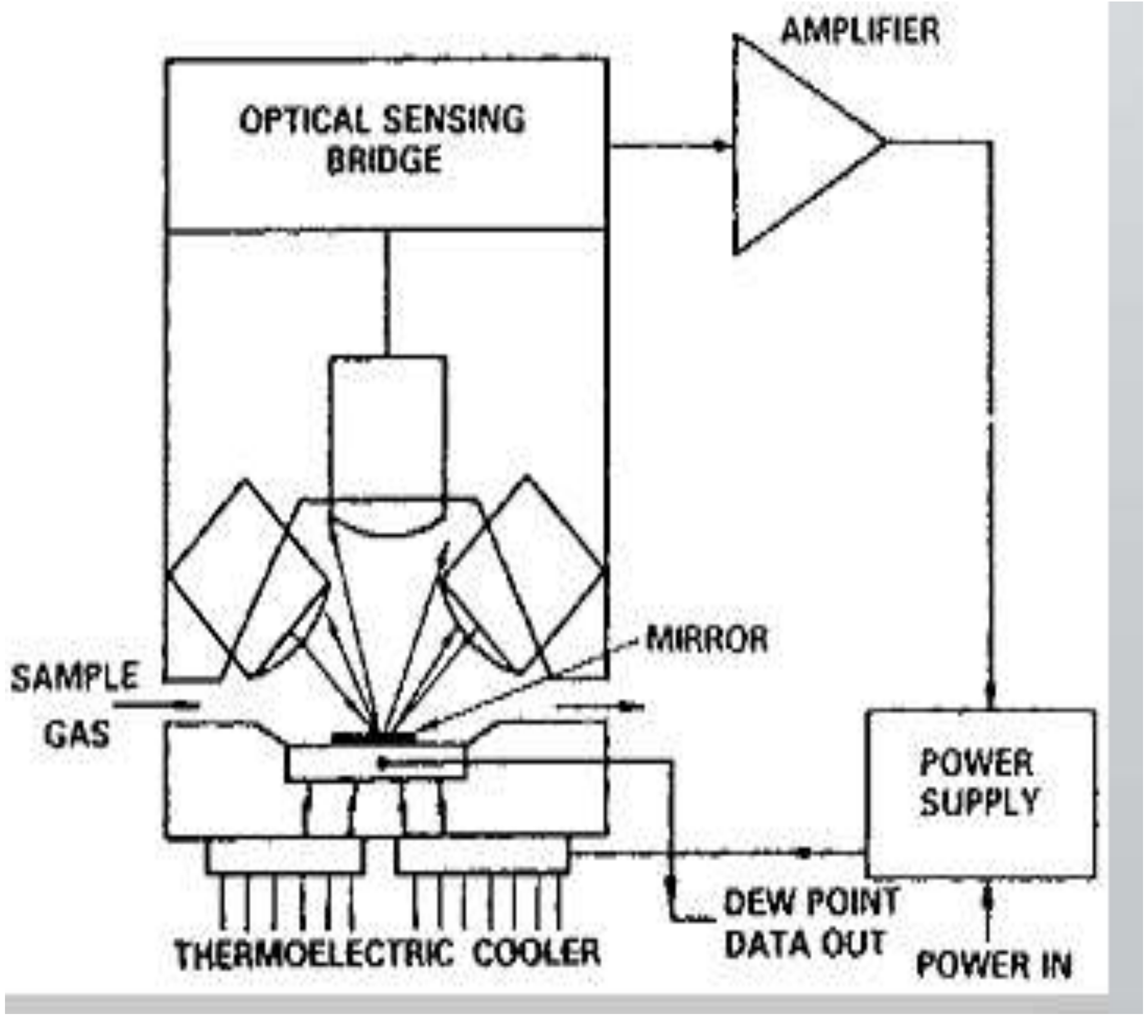
Disdvantages

- The measured medium is disturbed due to the act of measurement.
- The evaporation process at the wet bulb will add moisture to the air.
- It cannot be used in automation requirement situations.
- It cannot be used for continuous recording purpose.
- If the wick is covered with dirt, the wick will become stiff and its water absorbing capacity will reduce, however, a stiff/dirty wick will resume normalcy when boiled in hot water

Chilled mirror dew point hygrometer

- Dew point is the temperature at which a sample of moist air at constant pressure reaches water vapor saturation.
- At this saturation temperature, further cooling results in condensation of water.
- Chilled mirror dew point hygrometers are some of the most precise instruments commonly available.
- They use a chilled mirror and optoelectronic mechanism to detect condensation on the mirror's surface.
- The temperature of the mirror is controlled by electronic feedback to maintain a dynamic equilibrium between evaporation and condensation, thus closely measuring the dew point temperature.
- More recently, spectroscopic chilled-mirrors have been introduced. Using this method, the dew point is determined with spectroscopic light detection which ascertains the nature of the condensation. This method avoids many of the pitfalls of the previous chilled-mirrors and is capable of operating drift free.

- At a constant pressure, the temperature at which water vapor turns to liquid is positively correlated and proportional to the humidity.
- A Chilled Mirror Dew point hygrometer uses an optoelectronic sensor to detect whether there is dew on a glass mirror.
- Using a feedback control loop, the temperature of the mirror is raised and lowered until condensation occurs.
- This temperature is calibrated with a measurement of humidity.



- Advantages
- This type of humidity sensor is one of the most accurate sensors available.
- An accuracy of 0.2 °C is attainable with these devices

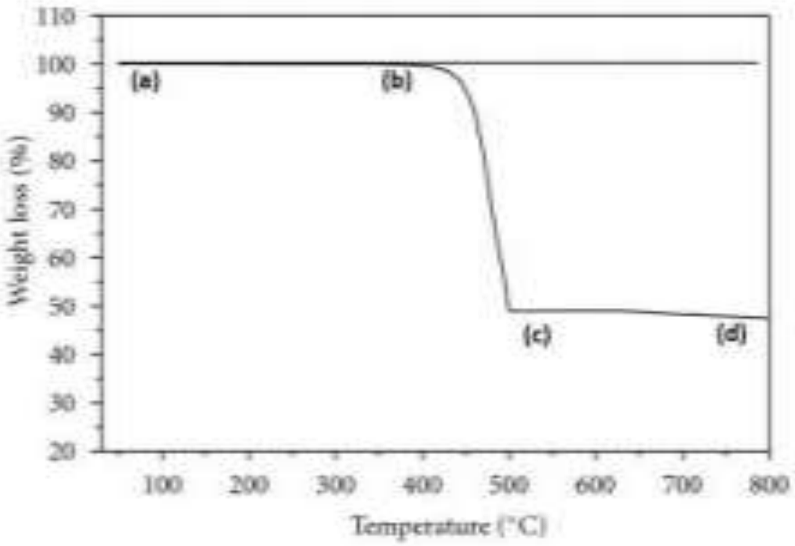
- **Disadvantages**
- These devices need frequent cleaning, a skilled operator and periodic calibration to attain these levels of accuracy.
- Even so, they are prone to heavy drifting in environments where smoke or otherwise impure air may be present.

Thermogravimetric analysis (TGA)

- In thermogravimetric analysis, the sample is heated in a given environment(air, N_2, CO_2, He,Ar, etc.) at controlled rate.
- The change in the weight of the substance is recorded as a function of temperature or time. The temperature is increased at a constant rate for a known initial weight of the substance and the change sin weights are recorded as a function of temperature at different time interval.
- This plot of weight change against temperature is called thermogravimetric curve or thermogram, this is the basic principle of TGA.

TGA Curve for AgNO3

- The horizontal portion of the curve indicates that, there is no change in weight (AB &CD) and the portion BC indicates that there is weight change.
- The weight of the substance (AgNO3) remains constant upto a temperature of 473°C indicating that AgNO3 is thermally stable upto a temperatureof473°C.
- At this temperature it starts losing its weight and this indicates that the decomposition starts at this temperature. It decomposes to NO2,O2 and Ag.
- The loss in weight continues upto 608°C and beyond this temperature the weight of the sample remains constant (stable residue of metallic silver), this is shown by the portion of the curve CD.

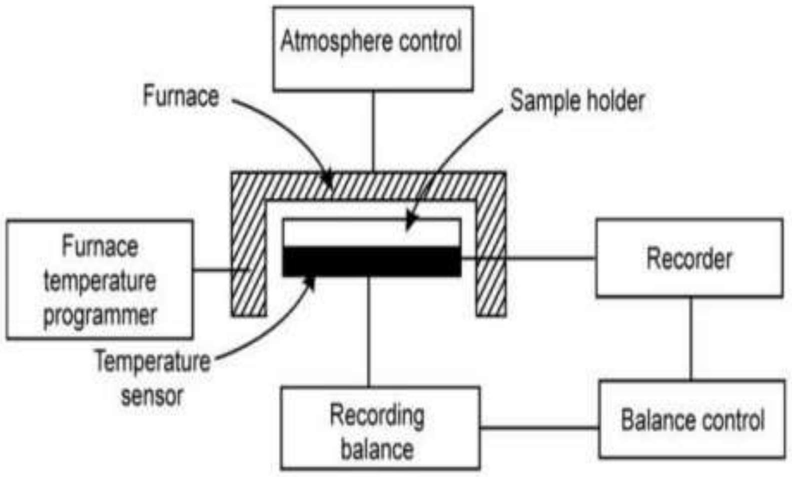


The diagram indicates the TGA curve for $AgNO_3$.

$$AgNO_3 \longrightarrow Ag + NO_2 + O_2$$

Instrumentation and working

- A furnace which can be heated so that the temperature gives linearity with time.
- **A furnace controlled thermo balance**
- A known weight of the sample is taken in a crucible(c), which is enclosed by a furnace(F).
- The furnace(F) temperature is raised slowly, the temperature of the sample and the corresponding weight are taken.
- A platinum/platinum rhodium thermocouple is used to measure the sample temperature, and the change in weights are found out by finding the beam deflection on adding a known weight to the pan.(i.e) the change in the weight are recorded from the beam deflection.
- **Recorder**: A recorder records the change in weight in y axis and w.r.to temperature on the x-axis. We get a thermogram.



Factors affecting the TG curve

- The factors which may affect the TG curves are classified into two main groups.

(1) Instrumental factors

(2) Sample Characteristics

(1) **Instrumental factors**

(a) Furnace heating rate

(b) Furnace atmosphere

(2) **Sample characteristics includes**

(a) Weight of the sample

(b) Sample particle size

Instrumental factors

- **Furnace Heating rate:**
- The temperature at which the compound (or sample) decompose depends upon the heating rate. When the heating rate is high, the decomposition temperature is also high.
- A heating rate of 3.5°C per minute is usually recommended for reliable and reproducible TGA.
- **Furnace atmosphere**:
- The atmosphere inside the furnace surrounding the sample has a profound effect on the decomposition temperature of the sample.
- A pure N_2 gas from a cylinder passed through the furnace which provides an inert atmosphere

Sample characteristics

- **Weight of the sample**:
- A small weight of the sample is recommended using a small weight eliminates the existence of temperature gradient through the sample.
- **Particle size of the sample:**
- The particle size of the sample should be small and uniform. The use of large particle or crystal may result in apparent, very rapid weight loss during heating.

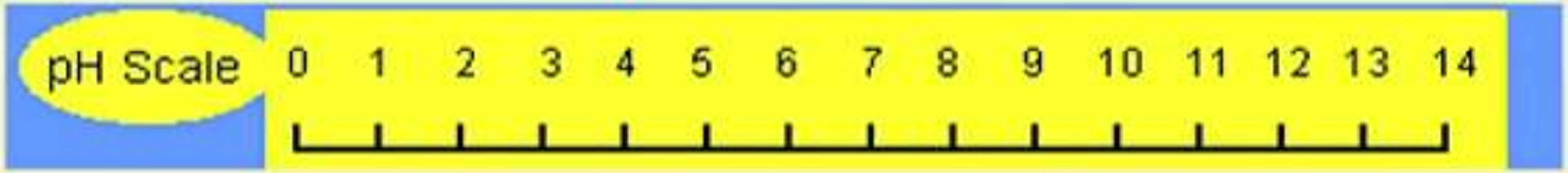
Applications of TGA

- From TGA, we can determine the purity and thermal stability of both primary and secondary standard.
- Determination of the composition of complex mixture and decomposition of complex.
- For studying the sublimation behaviour of various substances.
- TGA is used to study the kinetics of the reaction rate constant.
- Used in the study of catalyst: The change in the chemical states of the catalyst may be studied by TGA techniques. (Zn-$ZnCrO_4$) Zinc-Zinc chromate is used as the catalyst in the synthesis of methanol

Measurement of pH

- pH is the abbreviation of pondus hydrogenii
- pH is a unit of measure which describes the degree of acidity or alkalinity (basic) of a solution.
- It is measured on a scale of 0 to 14.
- The formal definition of pH is the negative logarithm of the hydrogen ion activity.
- $pH = -\log_{10}[H+]$
- If the H+ concentration is higher than OH- the material is acidic.
- If the OH- concentration is higher than H+ the material is basic.
- 7 is neutral, < 7 is acidic, >7 is basic
- The hydrogen ion concentration is in moles per liter. So, a pH of 4 will mean that the hydrogen ion concentration is 10^{-4} moles per liter or 0.0001 mole per liter.
- This is also equivalent to 0.0001 gram per liter of hydrogen ion, as molecular weight of hydrogen is one gram per mole.

pH Scale



- The pH values use a log to the base 10 scale
- Each pH unit is 10 times as large as the previous one
- A 10-fold change in concentration (say 0.1 to 1.0), the pH changes by one unit.
- A change of 2 pH units means 100 times more basic or acidic

	$[OH^-]$ concentration (mol/l)	pH	$[H^+]$ concentration (mol/l)		
1×10^{-14}	0.00000000000001	0	1	1 x 100	
1×10^{-13}	0.0000000000001	1	0.1	1×10^{-1}	
1×10^{-12}	0.000000000001	2	0.01	1×10^{-2}	
1×10^{-11}	0.00000000001	3	0.001	1×10^{-3}	Increasing
1×10^{-10}	0.0000000001	4	0.0001	1×10^{-4}	acidity
1×10^{-9}	0.000000001	5	0.00001	1×10^{-5}	
1×10^{-8}	0.00000001	6	0.000001	1×10^{-6}	
1×10^{-7}	0.0000001	7	0.0000001	1×10^{-7}	Neutral
1×10^{-6}	0.000001	8	0.00000001	1×10^{-8}	
1×10^{-5}	0.00001	9	0.000000001	1×10^{-9}	
1×10^{-4}	0.0001	10	0.0000000001	1×10^{-10}	Increasing
1×10^{-3}	0.001	11	0.00000000001	1×10^{-11}	basicity
1×10^{-2}	0.01	12	0.000000000001	1×10^{-12}	
1×10^{-1}	0.1	13	0.0000000000001	1×10^{-13}	
1 x 100	1	14	0.00000000000001	1×10^{-14}	

pH measurement

- The most common method of measuring pH is by glass cell and calomel cell electrodes used with a potentiometer device.
- And electrode is immersed in the solution, and electric potential is produced at the electrode which forms and electrolytic half-cell. This is the measuring cell.
- A second electrode is required to provide a standard potential and to complete the cell. This is the reference cell.
- The algebraic sum of the potentials of the 2 half cells is proportional to the pH of the solution.
- This is basically based on Nernst equation. $$E = E^0 + \frac{2.3RT}{nF} * \log a_{ion}$$
- So, E is the total potential between 2electrodes

- E_o is the stable potential of the reference electrode so, it will be normally known.
- α_{ion} is the activity of the specific ion concentration ($0 \leq \alpha \leq 1$). For hydrogen cells, it is hydrogen ion concentrations.
- R is the gas constant, 8.314 j/K/mole
- T is the absolute temperature, in K
- n is the charge of the measured ion
- F is the faraday's constant which is 96487 coloumbs per mole.

The entire term "2.3RT/nF" is called the Nernst factor. This term provides the amount of change in total potential for every ten-fold change in ion concentration.

For hydrogen ion activity, where n=1, the Nernst factor is 59.16 mV for every ten-fold change in activity at 25°C. This means that for every pH unit change, the total potential will change 59.16 mV.

$$E=E^0 + 2.3\frac{RT}{F}*\log a_{H+}$$

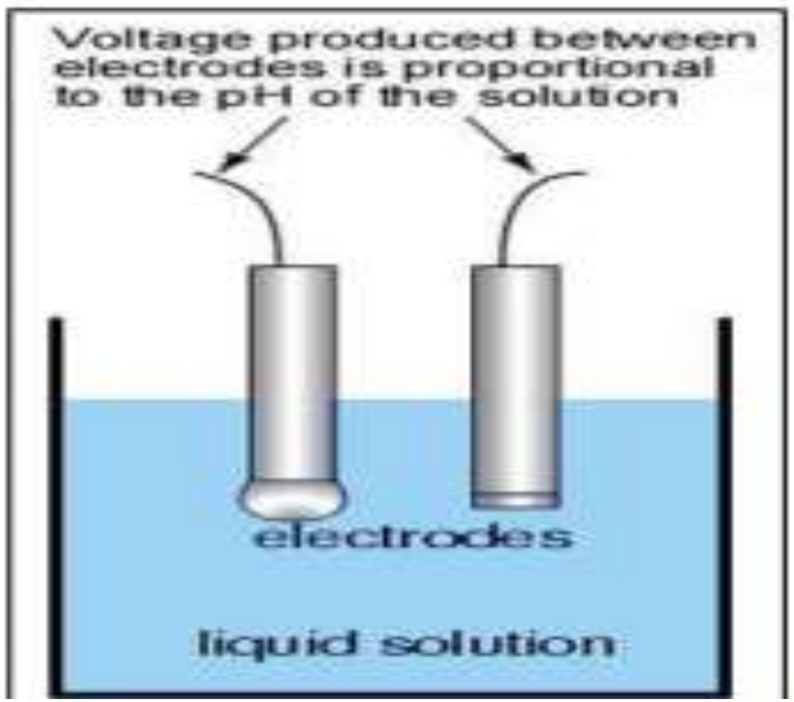
- Nernst factor is temperature dependent. So, whenever we measure pH using a commercially available pH meter, we also indicate temperature, because the Nernst factor has a temperature dependency unit.

pH measurement system

- A pH measurement system consists of three parts: a pH measuring electrode, a reference electrode, and a high input meter.
- The pH measuring electrode is a hydrogen ion sensitive glass bulb.
- The reference electrode output does not vary with the activity of the hydrogen ion.
- pH meter:
- A sample is placed in a cup and the glass probe at the end of the retractable arm is placed in it.
- The probe is connected to the main box.
- There are two electrodes inside the probe that measure voltage.
- One is contained in liquid with fixed pH.
- The other measures the acidity of the sample through the amount of H+ ions.

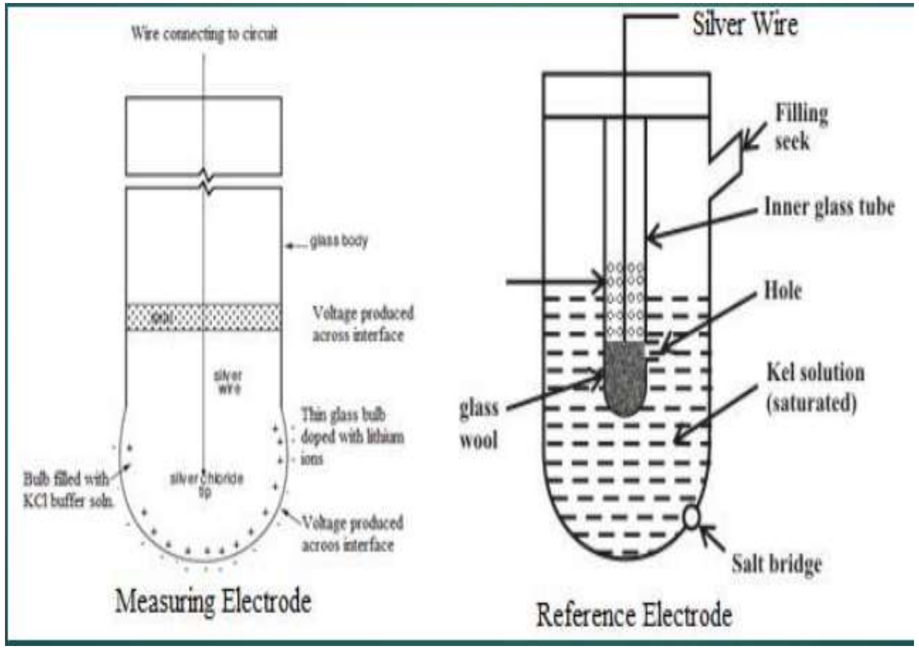
pH meter

- A voltmeter in the probe measures the difference between the voltages of the two electrodes.
- The meter then translates the voltage difference into pH and displays it on the screen.
- Before taking a pH measurement the meter must be calibrated using a solution of known pH.



Measuring electrodes.

- Measuring electrodes of specific make (thin ion selective glass)having buffer solution of constant H+ ion concentration and silverwire inside the glass bulb is dipped in the unknown solution where a potential is generated across the glass bulb.
- It forms one of the two half-cells. The measurement electrode's purpose is to generate the voltage used to measure the solution's pH.



- The reference electrode provides continuity to the electric circuit as one half-cell is unable to measure the potential generated.
- The reference electrodes are commonly of two types i)Calomel(Mercury–Mercurous Chloride)and ii) Silver–Silver Chloride electrode.
- The two sets of silver wires coming out from both the measuring electrode and reference electrode complete the circuit measuring the potential generated.
- The reference electrode consists of a chemical solution of neutral (7) pH buffer solution (usually potassium chloride) allowing exchange of ions with the process

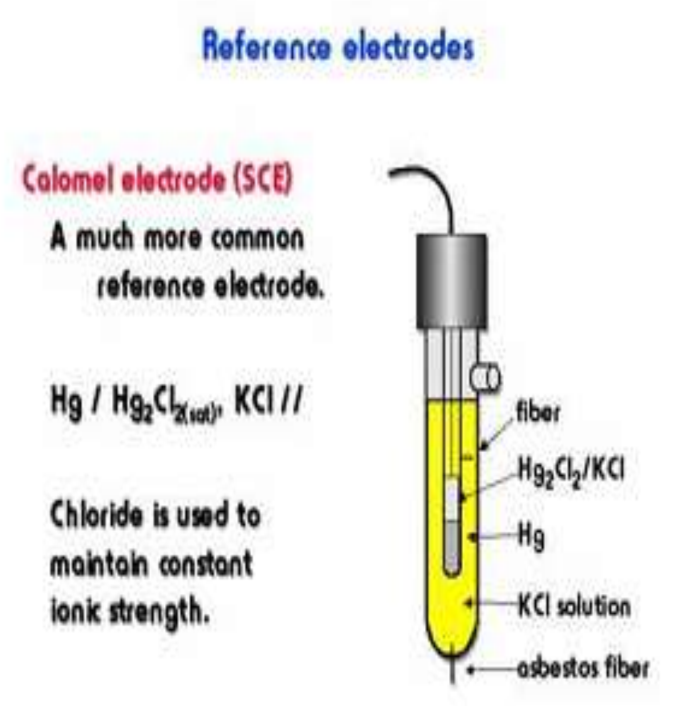
solution through a porous separator.

- The Saturated calomel electrode(SCE) is a reference electrode based on the reaction between elemental mercury and mercury(I)chloride.

- The aqueous phase in contact with the mercury and the mercury(I) chloride(Hg_2Cl_2, "calomel") is a saturated solution of potassium chloride in water.
- The electrode is normally linked via a porous membrane(the salt bridge) to the

Solution in which the other electrode is immersed.

- One drawback of calomel electrode is its mercury content which sometimes may create health hazard.
- Also one cause of malfunction is due to the trapped air bubbles.

Calomel electrode

- If it acts as cathode,
- $Hg_2Cl_2 \longrightarrow Hg_2^{2+} + 2Cl^-$ (ionization)
- $Hg_2^{2+} + 2e^- \longrightarrow 2\,Hg$ (reduction)
- Total reaction
- $Hg_2Cl_2 + 2e^- \longrightarrow 2\,Hg + 2Cl^-$
- $E_{CE} = E^o_{CE} - 0.0591 \log[cl^-]$ where n=2
- If it is acts as anode,
- $2\,Hg \longrightarrow Hg_2^{2+} + 2e^-$ (oxidation)
- $Hg_2^{2+} + 2Cl^- \longrightarrow Hg_2Cl_2$ (precipitation)
- $2\,Hg + 2Cl^- \longrightarrow Hg_2Cl_2 + 2e^-$
- $E_{CE} = E^o_{CE} + 0.0591 \log[cl^-]$ where n=2